PATENT SPECIFICATION

(11) 1380144

1380144

(21) Application No. 11583/72 (22) Filed 13 March 1972
(31) Convention Application No. 7108662 (32) Filed 12 March 1971
(31) Convention Application No. 7202012 (32) Filed 21 Jan. 1972 in
(33) France (FR)
(44) Complete Specification published 8 Jan. 1975
(51) INT CL² G01S 3/78
(52) Index at acceptance
H4D 271 710 722 746 771 775 782
G4H 1C 4C 5D 6A 6D 7B 7R 8B

(19)

(72) Inventors PATRICK SALLE and GUY SEITE

(54) APPARATUS FOR DETERMINING THE DIRECTION OF LUMINOUS RADIATION

(71) We, SOCIETÉ ANONYME D'ETUDES ET REALISATIONS NUCLEAIRES-SODERN of 10 Rue De La Passarelle 92-Suresnes, France, a French body corporate, do hereby declare the invention, for which we pray that a patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement:—

The present invention relates to apparatus for determining the direction of luminous radiation, such as that received from a luminous source very far away, with respect to a reference system, and more particularly relates to solar sensors provided with a digital output.

Such apparatus is for example used in a satellite in order to determine the direction of the sun with respect to the axes of the satellite and consequently to deduce the attitude of the satellite with respect to the sun.

Devices are already known for determining the angle λ made by the projection of the direction of the sun on a plane P with a reference direction situated in this plane. A device of this type is constituted by a parallelepiped block of quartz comprising on one face a narrow longitudinal slit and on the opposite face a system of tracks which are alternately opaque or transparent and are coded, preferably in a cyclic binary code. Behind each track is disposed a corresponding photosensitive cell so that, according to the angle of incidence of the radiation which illuminates the slit of the device, certain cells are masked whereas others are, on the contrary, irradiated by the luminous line formed by the slit through the block of quartz. All the cells taken together thus furnish in binary form a signal representative of the angle to be measured.

In this device, the plane P is orthogonal to the slit and the reference direction is, in this plane P, orthogonal to the plane containing the coded tracks. The use of two devices of this type whose slits are oriented perpendicular to one another thus furnishes, by the intersection of two planes each containing the sun, the direction of the luminous radiation.

This type of device nevertheless has a major disadvantage inherent in its construction: when the luminous source is not in a plane normal to the slit, parasitic optical couplings are produced through the block of quartz. Calculation shows that the output of the sensor depends not only on the angle λ sought, but also on the angle α of the direction of the sun with the plane P. Under these conditions, the measurement of the angle λ is accompanied by an error which is a function of the angle α, and this error is no longer negligible when the angle α exceeds a value of about 20°.

The invention proposes an apparatus for determining the direction of the luminous radiation in which this disadvantage is eliminated.

According to the invention, there is provided apparatus for determining the angle made by the projection on a reference plane of the direction of a very distant luminous source, in particular the sun, with a reference direction situated in this plane and comprising at least one rectilinear measurement slit producing a luminous line on a position coding system constituted by at least two tracks of opaque and transparent segments overlying respective photosensitive measurement cells, these tracks being longitudinally disposed perpendicular to the direction of the slit and situated in a plane perpendicular to the reference direction, characterised in that said slit and the coding system are supported by respective sheets each having parallel faces, the two sheets being parallel each to the other and spaced apart.

The use of two spaced apart sheets of quartz, each having parallel faces, separated by a gaseous medium or by a vacuum instead of a block of quartz, eliminates the previously mentioned parasitic optical couplings.

As the optical path is no longer contained integrally in the quartz, but is also in the gaseous medium or vacuum, this arrangement leads, on the other hand, to an increase in the length and in the width of the tracks for a given field of λ and α.

With a view to reducing the dimensions of the sensor for a given field, an embodiment of the invention herein described provides complimentary features comprising, on the one hand, inserting field masks between the coding system and the cells, and on the other hand, using two symmetrical diaphragms instead of just one.

Other features are also provided in an embodiment herein described for taking into account the albedo of the earth which, for a satellite in a low orbit, is seen under a wide angle and whose parasitic radiation disturbs the measurement.

Other particularities and advantages of the invention will become apparent from the following description given by way of non-limiting example in relation with the accompanying drawings.

In these drawings:

—Figure 1 is an explanatory schematic diagram for defining the angles α and λ.

—Figure 2 is a schematic perspective view of a sensor according to the invention.

—Figure 3 is a view of one of the sheets having parallel faces.

—Figures 4 and 5 are sections showing details of construction.

—Figure 6 is a section of the mounting frame of the sensor.

—Figure 7 represents the circuit relating to a measurement cell.

—Figure 8 represents a view from above of a simplified auxiliary sensor.

—Figures 9a and 9b are response curves of the auxiliary sensor.

—Figure 10 represents a circuit for producing the particular signals of the simplified auxiliary sensor.

—Figure 11 represents a schematic view of a modified sensor.

—Figure 12 represents another circuit for producing a particular signal with reference to the sensor of Figure 11.

—Figures 13 and 14 are curves for illustrating the operation of the modified sensor.

—Figure 15 shows another arrangement for the diaphragms of the sensor.

In the rectangular system of axes Ox, Oy, Oz shown in Figure 1, it is assumed that the axis Oz defines the reference direction with respect to which it is desired to measure the angle λ made by the projection Os on the plane xOz of the direction OS of the luminous source. The angle of the direction OS with the plane xOz is designated by α.

It is easy to see that if a rectilinear diaphragm is disposed along the axis Oy, the angle λ can be measured by means of a position coding device which locates the luminous trace L produced by this diaphragm in a plan H normal to the axis Oz.

Figure 2 shows schematically a perspective view of a device according to the invention. 10 and 20 designate two sheets having parallel faces, made of quartz and about 1.5 mm thick, this thickness being conditioned by the mechanical requirements of the sensor in its conditions of utilisation. These sheets 10 and 20 are mounted parallel to one another in a frame which will be described in more detail in Figure 6. The sheet 10 is provided on its lower face with a mask delimiting a rectilinear diaphragm 15, called herein a measurement diaphragm, in the form of a slit having for example a width of 0.1 mm and a length of about 40 mm. The sheet 20 bears on its upper face a position coding system 25, symmetrical about the axis AA with the exception of one extreme track, comprising tracks 22A, 22B, . . . 22G parallel with each other and perpendicular to the direction of the diaphragm 15, these tracks being coded, preferably in a reflected binary code. The lower face of the sheet 20 bears field masks 21, equal in number of the number of coded tracks, and centred on the axis of these tracks and profiled as indicated in Figure 3 so as to compensate for the variations of illumination intensity with the angle λ of incidence of the radiation. The coding system 25 and the masks 21 are obtained by metal deposition under a vacuum, or by photogravure techniques according to well known processes.

Finally, under the sheet 20 are disposed, on a common support 24, measuring or measurement cells 23A to 23G, for example of the photovoltaic type. Each of these cells is of elongated rectangular shape, having a width of about 2.5 mm, and is disposed directly under the corresponding coded track 22. Moreover, two other cells 40 and 23L, whose roles will be specified later on, are also disposed parallel to the preceding ones, the cell 40 serving as an auxiliary reference cell and the cell 23L co-operating with a track 22L used in a device for removing signal ambiguity. All these cells are connected to the circuit for producing the information, whose schematic diagram is shown in Figure 7.

It can be seen that the luminous beam passing through the diaphragm 15 determines on the coding system 25 of the sheet 20 a rectilinear luminous trace L. As a function of the position of this trace with respect to the axis AA, the measurement cells 23A to 23G are illuminated or not through the tracks of the coding system 25 and furnish at their terminals two-level binary signals representative of the angle λ to be measured.

Figures 3 and 4 show respectively a partial view of the lower face of the sheet 20 and an axial section of this sheet. Given

that, in accordance with Lambert's law, the illumination of a surface varies with the angle of incidence of the radiation, the coded tracks are given a width that increases in accordance with an inverse law as the distance from the axis AA increases; this is the role of the field masks such as 21 which delimit strips centred on the longitudinal axis of the cells 23 and which have a profile conforming to this inverse law.

In the view of Figure 3 can be seen the coding system provided on the upper face of the sheet 20 and visible by transparency.

The disposition of the field masks 21 on the lower face of the sheet 20 also has a second advantage namely to permit, since this lower face of the sheet 20 is so close to the cells, a reduction in the required width of the cells for a field of given angular amplitude α, whereas in their absence, it would also be necessary to take into account the shift due to the refraction in the quartz, over the entire width of a track.

Figure 5, which is a cross-section of the apparatus, shows the use of two slits 15A, 15B symmetrically disosed with resect to the axis AA when the angular field λ is large, the slit 15A being for example used for the angles $\lambda>0$, and the slit 15B for the angles $\lambda<0$. This arrangement of two slits has the advantage over the arrangement having a single, centrally disposed slit that the length of the cells 23 can be shorter. With respect to the cell length necessary with a single central slit, Figure 5 shows at G the saving in length achieved.

It will be appreciated that in order to obtain good accuracy, it is necessary, on the one hand, that the luminous trace L on the plane of the coding system 25 be perfectly parallel to the transition lines of this system (which limit the opaque and transparent regions) and, on the other hand, that the cells 23 be themselves suitably positioned with respect to the tracks 22 with which they co-operate. Any obliqueness of the trace L on the axis AA would lead to measurement errors which would be difficult to interpret.

A means of satisfying this last condition is to form all the cells 23 as a group on a common support: in particular these cells can be obtained for example by a single diffusion of impurities onto a common substrate 24 constituted by a plate of silicon, in accordance with the technique known as the "planar" technique with the aid of a mask, in order to constitute junctions having the same distances between their axes as the tracks of the coded system.

With a view to eliminating tht ambiguities in the reading of the position of the luminous line L on the coded system 25, a supplementary track 22L is also provided, co-operating with the cell 23L. This track 22L is an incremental track encoded similar to tracks 22A to 22G but offset by a suitable fraction of an opaque-to-transparent step with respect to the track 22A of lowest rank in the coded system, and the cell 22L is connected to the decoding circuits of a device for removing signal ambiguity which device is described with reference to Figure 7 but does not form part of the invention.

Furthermore, as the elements 10, 20 and 24 are individually adjustable with respect to each other, their optimal relative position can be obtained during their assembly in a common frame. Figure 6 shows a transverse section of such an assembly in a frame 30 made of ferronickel, e.g. Invar (Registered Trade Mark) and of general parallelepiped shape. The sheets 10 and 20 rest on bearing faces 31, 32 carefully machined parallel to each other, and these sheets are held by longitudinal pieces 33, 34. The plate 35 supporting the cells is also held in a similar manner by transverse pieces 36.

Provision is made during assembly for the possibility of rotating the upper sheet 10 containing the diaphragm 15 in order to be able to make this diaphragm perfectly parallel to the transition lines of the coded system 25.

In a practical example, the distance between the sheets 10 and 20 is about 10 mm., and the sheets have dimensions of 40 mm by 50 mm.

The space 37 formed at the lower part is intended to house the electronic circuits for processing the signals.

When the field envisaged for the solar sensor is large, there is a difficulty due to the presence of radiation from parasitic sources, and in particular the albedo of the earth which is seen from the satellite generally with a much wider angle than the sun, all the more so when the orbit is lower.

In certain earth-sun-satellite configurations, there is thus a risk that the sensor will furnish erroneous indications if precautions are not taken.

For this purpose, the cell 40, visible in Figure 2, is used as a reference cell. This reference cell, which is of the same type and of the same dimensions as the measuring cells 23, is disposed parallel to those cells, but is preceded by a transparent track 22R so that it is always lit by the luminous line L, possibly through a field mask 21, whatever be the position of this line in the field of the apparatus. On each channel relating to a measuring cell 23, the output signal furnished by this reference cell 40 is used to produce a reference level at one of the inputs of a comparator circuit at the other input of which is applied the output signal from that measuring cell 23. According to the result of this comparison, a signal S appears at the output of the comparator having a logic level 1 or 0 according to

whether the respective measuring cell 23 is irradiated or not by the luminous line L.

Figure 7 shows the corresponding circuit. The voltage VR furnished by the reference cell 40 is applied to the terminals of a load resistance 42R, and then amplified in the amplifier 41R. In the same manner, the signal from a measuring cell 23, for example 23A, is amplified by the amplifier 41A. The outputs of the amplifiers 41R and 41A are connected to the inputs of the voltage comparator 45A. This comparator comprises for example the parallel arrangement of two transistors T1, T2 and an output transistor T3. In operation, if the cell 23A is for example illuminated (and its output is greater than the threshold set by cell 40), the transistor T2 is saturated, the transistor T1 blocked and the transistor T3 blocked. A signal S of logic level 1 consequently appears at its collector. On the contrary, if the cell 23A is in shadow, the transistor T2 is blocked, the transistor T1 is saturated and the transistor T3 is also saturated, which leads to a signal S of logic level 0 at its collector.

The signals S at the output of the comparators 45A to 45G constitute the binary data representative of the angle λ to be measured.

The use of a reference cell which is always illuminated thus has the advantage of furnishing a variable threshold for comparison, for taking into account the albedo of the earth, and the advantage of permitting a surer discrimination of the levels of the signals coming from the measuring cells. It also enables the aging of the cells to be compensated for, as well as the variations in illumination due to the angle of incidence α of the radiation. It is advantageous to dispose the tracks 22A, 22L and 22R side by side in the centre of the coded system with a view to limiting the errors due to non-parallelism of the luminous line with the transition lines of the coded system.

There still exists a cause of error when the angle α (Figure 1) exceeds the maximum value α_M of the field provided for the apparatus. It then happens, when the angle of incidence of the radiation is too great, that the luminous line only cuts some but not all of the tracks of the system 25; the cells thus left in shadow are then going to furnish a logic signal 0 as if they were masked by coding system and the output information will be false if the apparatus is not capable of recognising that the field has been exceeded.

To avoid such errors, an auxiliary sensor is provided, analagous to the main measurement facilities, but simplified relative thereto with a view to furnishing not a measurement signal representing the angle α but a signal indicating the presence of the luminous line in the useful field of view of the apparatus. Figure 8 shows schematically a view from above of the auxiliary sensor. A diaphragm 50, called herein the control diaphragm, is oriented along the direction Ox (Figure 1) and the plane of the cells is orthogonal to the reference axis Oz. Two cells 53A, 53B are illuminated by the luminous line through two openings 51A, 51B formed in a mask supported by the lower face of the sheet 20. These openings, elongated in the direction perpendicular to the direction of the diaphragm 50, have their length delimited on the one hand by an axis BB of the apparatus perpendicular to the axis AA), and on the other hand by the position of the luminous line corresponding to the maximum permissable field α_M for the measuring sensor, α_M being the angle made by the projection of the direction of the sun on the plane of symmetry of the measuring sensor (plane yOz) with the reference direction (Oz). Several cases can result, namely:

a) when $\alpha=0$, the two cells 53 are both irradiated by the luminous line whose width is not infinitely small.

b) when $0<\alpha<\alpha_M$, one of the two cells is illuminated by the luminous line.

c) when $\alpha>\alpha_M$, neither of the cells 53 is illuminated.

Under these conditions, by taking the sum and the difference of the output signals SA and SB of these two cells, it can be deduced, by logical comparison, whether or not the luminous line falls within the useful field of the apparatus, and more particularly, which of the preceding cases is present. Figures 9a and 9b show respectively the shape of these signals, namely the sum $S_1=S_A+S_B$ and the difference $S_2=S_A-S_B$, as a function of the angle α.

It should be noted that for $\alpha<\alpha_M$, the signal S_1 has a constant value and that beyond the field α_M, its value becomes 0. This signal S_1 is consequently usable, when it becomes smaller than a certain threshold T, as an inhibit signal I for blocking the outputs of all the comparator stages (45, Figure 7) relating to the cells of the measuring sensor. When all the outputs fall to the logical level 0, this means that the sun has left the useful field of the apparatus.

It is also interesting in satellites having a spinning motion to obtain a signal when the sun is contained in a characteristic plane such as the plane orthogonal to the direction of the diaphragm of the measuring sensor, for which plane $\alpha=0$. This is easily achieved from the signals S_1 and S_2 since cells 53A and 53B are both irradiated (case (a) above), wherein $S_2=S_A-S_B=0$ and $S_1=S_A+S_B=S$, which may be regarded as logic 1. It is then sufficient to invert the signal S_2 and to apply the signals $\overrightarrow{S_2}$ and S_1 to an AND circuit in order to have an output signal N of logic

level 1 only when α passes through the value O.

The circuit for producing the inhibit signal I and the signal N representing orthogonality (i.e. $\alpha=0$) is shown in Figure 10. From the signals SA and SB generated by the cells 53A and 53B, two operational amplifiers one arranged as a summing amplifier 51 and the other as a differential amplifier 52, produce the signals $S_1=S_A+S_B$ and $S_2=S_A-S_B$ The signal S_1 is applied to a threshold circuit 54 at the output of which the inhibit signal I appears. This signal is made positive if necessary and applied to the base of the transistor T_3 of the comparators 45 (Figure 7) which plays the role of a gate circuit and which when it is saturated furnishes a signal of logic level O.

The signals S_1 and S_2 are also applied to the inputs of an AND circuit 56; the first directly and the second via the intermediary of an inverter 55. At the output of the circuit 56 appears the signal of orthogonality N.

Furthermore, in the case of a satellite provided with spin, it is not necessary to define the useful transverse field of the apparatus since the measurement always takes place when the sun passes through the same plane, which is preferably chosen perpendicular to the direction of the measuring diaphragm, that is to say, with reference to Figure 1, perpendicular to the direction Oy assuming that the satellite spins about an axis parallel to Ox. Nevertheless the detection of the passage of the sun through this characteristic plane can be performed by means of the auxiliary sensor described above.

According to a complimentary feature of the invention particularly applicable to such a satellite, or more generally, when it is a question of measuring the angle of incidence of a luminous ray in a given reference plane, the measuring apparatus and the auxiliary sensor are combined into a single unit in order to simplify the manufacture and the mechanical adjustment, and to reduce the size.

The apparatus then comprises on the same sheet having parallel faces (i.e. on quartz sheet 10) at least one control diaphragm for the auxiliary sensor, disposed orthogonal to the direction of the main or measuring diaphragm 15; and on the support common to all the measuring and reference cells there is provided an associated control cell disposed parallel to the other cells and disposed in a plane parallel to the reference plane xOz and passing through the longitudinal axis of the control diaphragm.

This associated control cell is illuminated through a transparent track in the sheet 20 having a width at least equal to half the width of the luminous line formed by the control diaphragm.

The actual instant at which the sun passes through the plane of normal incidence is detected when the light received through the control diaphragm by the control cell increases to a valve equal to a definite proportion of the light received by the reference cell through the diaphragm which is associated with it.

In order to avoid, when the angle α passes through high values, that the light coming from the measuring diaphragm or diaphragms and falling on the control cell furnishes a signal which could be interpreted as a signal of orthogonality ($\alpha=0$), electronic means prevent the signal furnished by the reference cell from descending below a predetermined threshold value. This threshold value is chosen such that it is always greater than the value of the control voltage in such conditions, and also such that it causes the blocking of the outputs of the measuring cells when the sun leaves the useful field of measurement.

Under certain conditions, it can be useful to know the instant of the passage of the sun through the plane of normal incidence ($\alpha=0$) when the sun is outside the useful field of measurement. The apparatus is then modified so that the reference cell is no longer illuminated through the measuring diaphragm when the angle α is 0, but through two parallel slits provided directly above the ends of this cell, and preferably oriented at 45° from the measurement diaphragm.

The following description will be limited to the case in which the passage of the sun through the plane of normal incidence is detected.

In Figure 11, where the same references have been used as in Figure 2, the sheet 10 can be seen bearing, in addition to the measurement diaphragm or slit 15, a second or control diaphragm or slit 50 disposed orthogonally and symmetrically to this diaphragm 15. This diaphragm 50 is for example arranged in the form of a rectilinear slit having a length of about 2.5 mm and a width of about 0.15 mm. With this diaphragm 50 is associated a transparent track 22S formed on the sheet 20 such that, under the normal incidence when $\alpha=0$, the luminous source illuminates through this track a supplementary photovoltaic cell 53 (i.e. the associated control cell for the control slit 50) parallel to the other cells, namely the measurement and reference cells 23 and 40. The reference cell 40 is, in the example shown, disposed between the control cell 53 and the measurement cells 23. The transparent track 22S has a width at least equal to half the width of the luminous line formed by the diaphragm 50, that is to say greater than 0.3 mm about.

The control cell 53 therefore only furnishes a signal signifying orthogonality if the luminous line produced by the diaphragm 50 falls on the surface at the normal incidence; this signal is then used, when the apparatus is set to monitor spinning motion, for enabling the comparator circuits 45 of Figure 7 only when α is 0 (in the place of the signal 1 which is used in normal operation such that the comparator circuits are enabled only when $\alpha < \alpha_m$). However, for large angles α, there is a risk that this cell will be traversed by the luminous line produced by the measurement diaphragm 15, and will furnish a "parasite" signal which, although of small amplitude, could be interpreted as an effective signal detecting the passage through the normal incidence.

To avoid this disadvantage, it is arranged to enable the comparator circuits only when the signal coming from the control cell 53 becomes greater than a comparison signal produced from the signal coming from the reference cell 40 and replaced by a minimum threshold value VR_m, when this latter signal falls below this value VR_m. This threshold value is chosen sufficiently high to prevent any untimely enabling of the comparator circuits when the sun is not effectively in the plane of normal incidence.

The unblocking signal is obtained by means of the circuit shown in Figure 12. The signals coming from the control cell 53 and the reference cell 40 are respectively applied to the inputs of amplifiers 41C and 41R. This later amplifier has a threshold voltage VR_m which is fixed by means of a potential divider 46 supplied from a higher voltage U and followed by an impedance adapter circuit 47. The response curve of this amplifier is shown in Figure 13 where it is seen that the output voltage V_R remains equal to the threshold value VR_m as long as the current i_R furnished by the reference cell 40 remains lower than a value i_m corresponding to a predetermined illumination, and then increases normally.

The voltage V_C at the output of the amplifier 41C and the voltage V_R are applied to the inputs of a voltage comparator 60. This comparator furnishes a calibrated pulse J of logic level 1 when the voltage V_C passes through the reference voltage V_R in the increasing direction. Otherwise, it furnishes a signal J of logic level 0 which can play the role of an inhibit signal for the output of the measurement cells.

In the diagram of Figure 14, the output voltage V_C of the control cell 53 has been plotted as a function of the angle α represented on the abscissa, for two values λ_1, λ_2 of the angle λ to be measured. It can be seen that the instant of triggering of the reading of the measurement cells by unblocking their outputs is obtained when the voltages V_C and V_R are equal, approximately for the same value $\alpha=0$.

Since the threshold amplifier substitutes for the voltage V_R proportional to the illumination of the reference cell 40, a minimum voltage of predetermined value VR_m when V_R falls below this value, this eliminates the production of erroneous signals J, i.e. at angles α different from 0, under the effect of the light received by the control cell 53 through diaphragms other than its associated diaphragm 50, or resulting from the terrestial albedo or from any other source of parasitic light.

This device thus enables the outputs of the measurement cells 23 to be maintained at a logic level 0, even in the presence of parasitic light sources when the sun leaves the field of λ.

Figure 15 shows a modified arrangement of the diaphragms on the sheet 10 that allows a field for the auxiliary control part of the apparatus which is larger than the field for the measuring part of the apparatus. In this case, two control diaphragms 50A, 50B are used, disposed on the axis of the associated control cell 53, directly above the ends of this cell. These diaphragms have for example a length of about 2.5 mm and a width of 0.15 mm. The reference cell 40 is no longer illuminated through the measurement diaphragm 15, but through two parallel slits 65A, 65B similarly disposed directly above the ends of the reference cell 40. These slits can be oriented parallel to the diaphragm 15, but calculation shows that in order to limit the inevitable positioning the various components without errors, and without leading to high illumination of the cell 53 under very oblique angles of incidence, it is more advantageous to orient them at 45° from the direction of this diaphragm.

WHAT WE CLAIM IS:—

1. Apparatus for determining the angle made by the projection on a reference plane of the direction of a very distant luminous source, in particular the sun, with a reference direction situated in this plane and comprising at least one rectilinear measurement slit producing a luminous line on a position coding system constituted by at least two tracks of opaque and transparent segments overlying respective photosensitive measurement cells, these tracks being longitudinally disposed perpendicular to the direction of the slit and situated in a plane perpendicular to the reference direction, characterised in that said slit and the coding system are supported by respective sheets each having parallel faces, the two sheets being parallel each to the other and spaced apart.

2. Apparatus according to claim 1, characterised in that, between the coding system and

the measurement cells is inserted, for each track, a field mask delimiting a transparent band centred on the longitudinal axis of the corresponding cell and profiled so as to compensate for the variations in illumination with the angle of incidence of the radiation.

3. Apparatus according to claim 2, characterised in that the coding system and the field masks are supported by the opposite parallel faces of one of said sheets.

4. Apparatus according to any preceding claim, characterised in that it comprises an auxiliary reference cell, disposed parallel to the measurement cells and always illuminated by the luminous line.

5. Apparatus according to any preceding claim, characterised in that all the cells comprise collectively a single diffusion on a common substrate.

6. Apparatus according to any preceding claim, characterised in that it comprises a second rectilinear measurement slit disposed parallel to the first measurement slit on the same sheet, the two measurement slits being disposed symmetrically relative to a central axis of that sheet.

7. Apparatus according to claim 4 or to claim 5 or 6 when appended to claim 4, characterised in that each measurement cell and the reference cell are connected to a voltage comparator circuit which furnishes an output signal of logic level 1 or 0.

8. Apparatus according to claim 4, characterised in that it comprises two further cells illuminated through two elongate openings parallel to the direction of the measurement slit, these openings each having one end on a common axis and having their other ends determining the useful field of view of the apparatus.

9. Apparatus according to claim 8, characterised in that it is provided with a control slit oriented perpendicular to the measurement slit, for illuminating said two further cells through said openings.

10 Apparatus according to claim 8, characterised in that the outputs of the two further cells are both connected to a summing operational circuit and to a differential operational circuit.

11. Apparatus according to claim 10, characterised in that the output of the summing circuit is connected, via the intermediary of a threshold circuit, to a gate circuit connected to the output of a voltage comparator circuit, the inputs of said voltage comparator circuit being supplied on the one hand by said reference cell and on the other hand by said measurement cells.

12. Apparatus according to claim 10 or 11, characterised in that the summing and differential circuit outputs are connected, the first directly and the second via the intermediary of an inverter, to an AND circuit.

13. Apparatus according to claim 4, characterised in that it comprises, on the same said sheet as the first-mentioned measurement slit, a control slit orthogonal to the direction of said first-mentioned measurement slit, and, on the support common to the measurement cells and reference cell, a control cell parallel to the preceding cells and disposed in a plane parallel to the reference plane and passing through the axis of said control slit.

14. Apparatus according to claim 13, characterised in that said same sheet is provided with two supplementary slits, the two supplementary slits being disposed directly above the opposite ends of the reference cell, the length of the measurement slit being limited to be directly above only the measurement cells.

15. Apparatus according to claim 14, characterised in that said supplementary slits are oriented at 45° with respect to the direction of the measurement slit.

16. Apparatus according to any of claims 13 to 15, characterised in that the control cell and the reference cell are connected to the inputs of a voltage comparator whose output signal is applied to a gate circuit connected to the output of the measurement cells.

17. Apparatus according to claim 16, characterised in that an amplifier giving at least a minimum threshold output is connected between the reference cell and the voltage comparator.

18. Apparatus substantially as described hereinbefore with reference to and as illustrated in Figures 2 to 7 of the accompanying drawings.

19. Apparatus substantially as described hereinbefore with reference to and as illustrated in Figures 2 to 7 as modified as hereinbefore described with reference to and as illustrated in Figures 8, 9a, 9b and 10 of the accompanying drawings.

20. Apparatus substantially as described hereinbefore with reference to and as illustrated in Figures 2 to 7 as modified as hereinbefore described with reference to and as illustrated in Figures 11, 12, 13 and 14 of the accompanying drawings.

21. Apparatus substantially as described hereinbefore with reference to and as illustrated in Figure 15 of the accompanying drawings.

A. A. THORNTON & CO.

Printed for Her Majesty's Stationery Office, by the Courier Press, Leamington Spa, 1975.
Published by The Patent Office, 25 Southampton Buildings, London, WC2A 1AY, from which copies may be obtained.

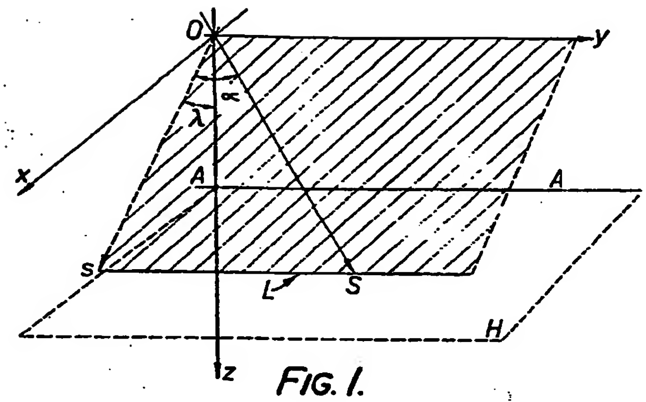
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FIG. 1.

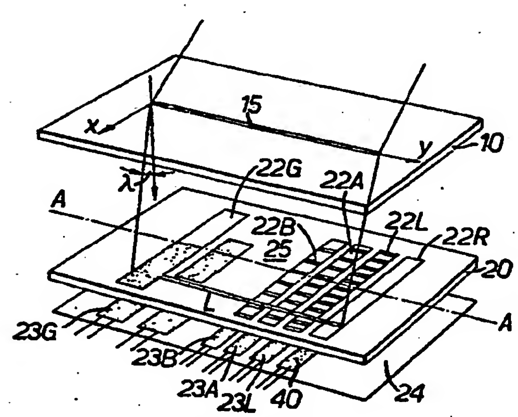
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FIG. 2.

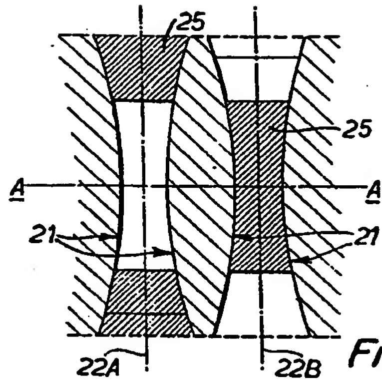


FIG. 3.

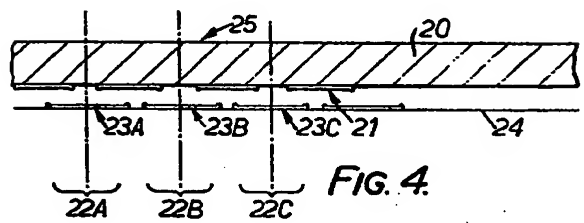


FIG. 4.

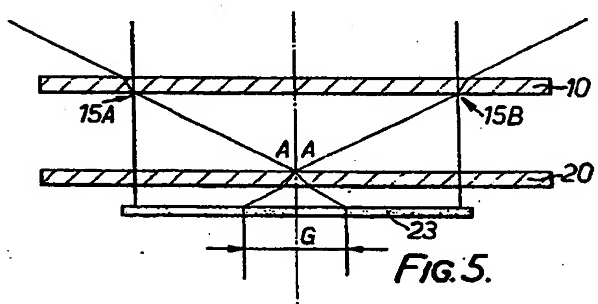
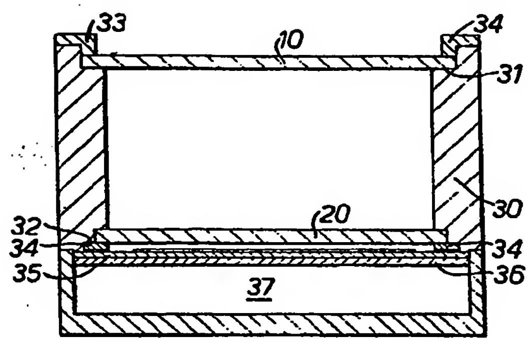


FIG. 5.


33
10
34
31
30
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32
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35
34
36
37

FIG. 6.

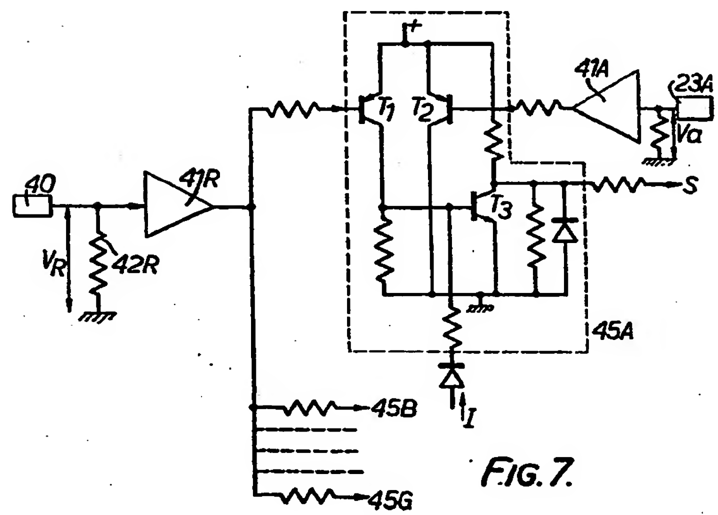
+
T_1
T_2
41A
23A
Va
40
41R
S
T_3
V_R
42R
45A
I
45B
45G

FIG. 7.

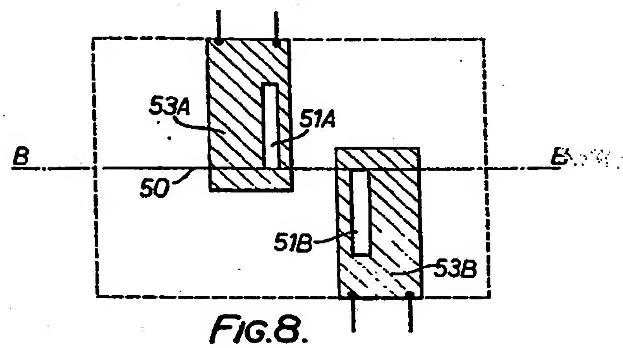

FIG. 8.

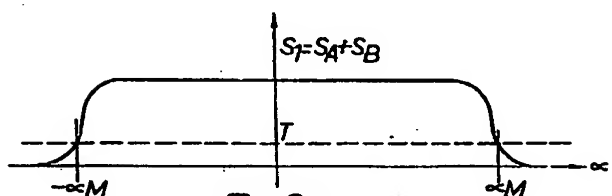

FIG. 9a.

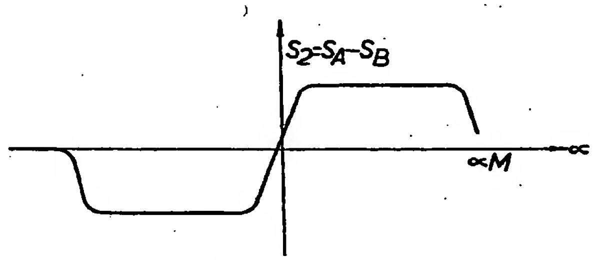

FIG. 9b.

1380144 COMPLETE SPECIFICATION

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Sheet 5

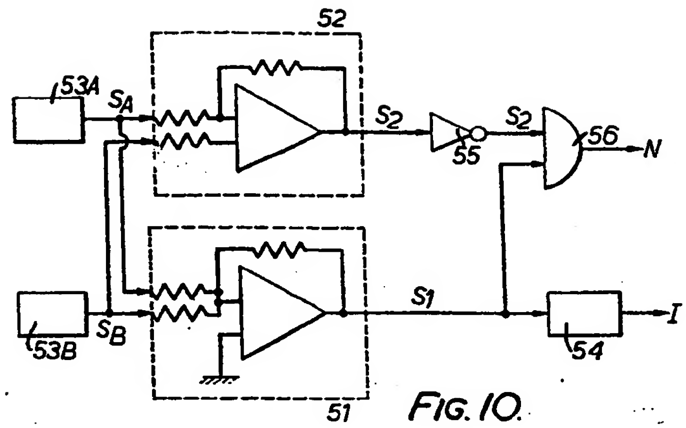

FIG. 10.

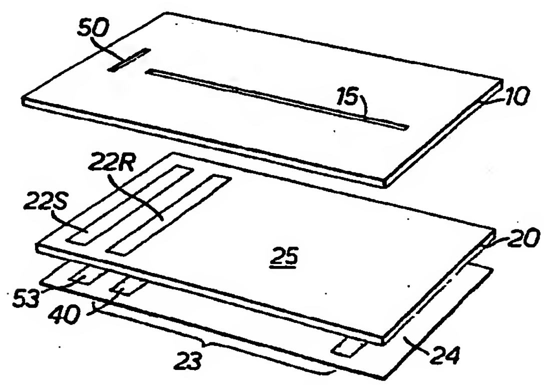

FIG. 11.

1380144 COMPLETE SPECIFICATION
6 SHEETS *This drawing is a reproduction of the Original on a reduced scale*
Sheet 6

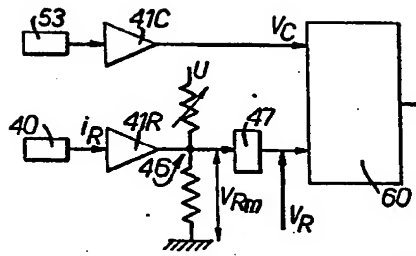

FIG. 12.

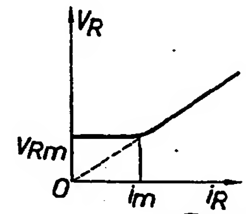

FIG. 13.

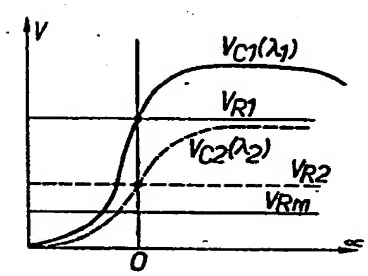

FIG. 14.

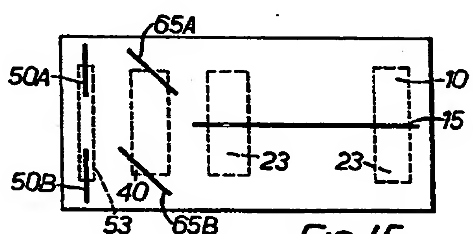

FIG. 15.

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